Exclusive lepton pair production in pp collisions?

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HELMHOLTZ
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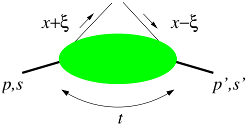
1. Brief introduction: GPDs and Compton scattering
2. Exclusive photoproduction of lepton pairs
3. Photoproduction in pp collisions
4. J/Ψ production
5. Summary

Generalized parton distributions in a nutshell

- GPDs $\leftrightarrow$ matrix elements $\langle p'|\mathcal{O}|p\rangle$
  $\mathcal{O}$ = non-local operator with quark/gluon fields
  e.g. $\bar{q}(-z)\, z_\mu \gamma^\mu\, q(z)|_{z^2=0}$



  - $p \neq p'$ $\rightsquigarrow$ depend on two momentum fractions x, ξ and on $t = (p-p')^2$, can trade for transverse mom. transfer $\boldsymbol{\Delta} = \boldsymbol{p}' - \boldsymbol{p}$
  - for unpolarized partons two distributions:
    - H conserves proton helicity
    - E responsible for proton helicity flip

Physics

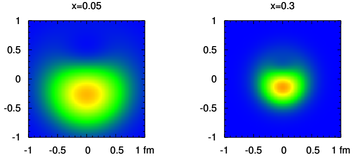
1. Fourier transform from $\mathbf{\Delta}$ to impact parameter $\boldsymbol{b}$
   $\rightsquigarrow$ transverse spatial distribution of partons in proton correlated with their longitudinal momentum
2. spin structure: information on orbital angular momentum
   Ji's sum rule:

$$J^q = \frac{1}{2}\int dx\, x\,(H^q + E^q)\Big|_{\substack{t=0\\ \xi=0}} \qquad J^g = \frac{1}{2}\int dx\,(H^g + E^g)\Big|_{\substack{t=0\\ \xi=0}}$$

   $J^{q,g} =$ contribution from helicity and o.a.m.
3. combine 1 and 2:

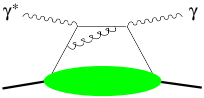
   Fourier transform of E : shift of transverse density in transversely polarized proton

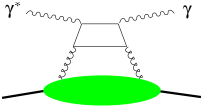
$(d-\bar{d})$ density in transverse plane



Processes

factorization theorems: GPDs appear in hard exclusive processes





- Compton scattering:

$\gamma^* p \to \gamma p$	DVCS	in $\ell p \to \ell\gamma p$
$\gamma p \to \gamma^* p$	Timelike Compton Scattering	in $\gamma p \to \ell^+\ell^-$
$\gamma^* p \to \gamma^* p$	double DVCS	in $ep \to e\,\mu^-\mu^+\,p$

Processes

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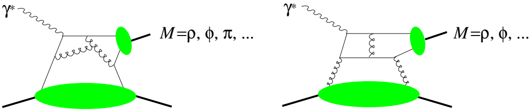


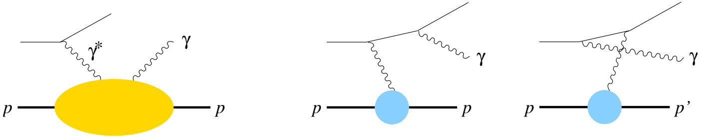
- Compton scattering:

$$\begin{array}{rll} \gamma^* p \to \gamma p & \text{DVCS} & \text{in } \ell p \to \ell\gamma p \\ \gamma p \to \gamma^* p & \text{TimelikeComptonScattering} & \text{in } \gamma p \to \ell^+\ell^- \\ \gamma^* p \to \gamma^* p & \text{double DVCS} & \text{in } ep \to e\,\mu^-\mu^+\,p \end{array}$$

- light meson production $\gamma^* p \to \rho\, p$, $\pi\, n$, ...
- heavy mesons: $\gamma p \to J/\Psi\, p$, $\Upsilon\, p$
  photo- or electroproduction

Deeply virtual Compton scattering

- competes with Bethe-Heitler process at amplitude level



- cross section for $\ell p \to \ell \gamma p$

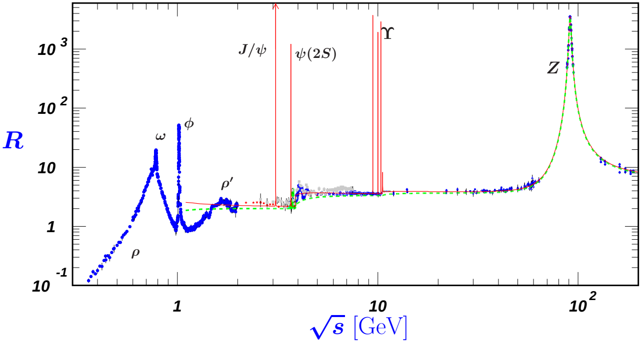
$$\frac{d\sigma_{\mathrm{VCS}}}{dx_B\, dQ^2\, dt} : \frac{d\sigma_{\mathrm{BH}}}{dx_B\, dQ^2\, dt} \sim \frac{1}{y^2}\frac{1}{Q^2} : \frac{1}{t} \qquad\qquad y = \frac{Q^2}{x_B s_{\ell p}}$$

- small y: σ_{VCS} dominates
  moderate to large y: get VCS via interference with BH
  $\rightsquigarrow$ separate $\mathrm{Re}\,\mathcal{A}(\gamma^* p \to \gamma p)$ and $\mathrm{Im}\,\mathcal{A}(\gamma^* p \to \gamma p)$
  $\rightsquigarrow$ most direct connection with GPDs

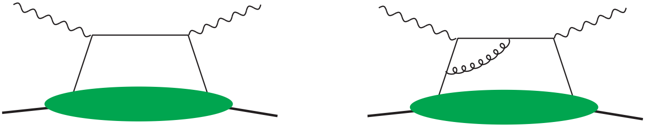
How large is “large”?

Q: which Q^2 is required for TCS to be described by parton-level calculation?

A: cannot say from theory $\rightsquigarrow$ take Drell-Yan and $e^+e^- \to$ *hadrons* as phenomenological indicators

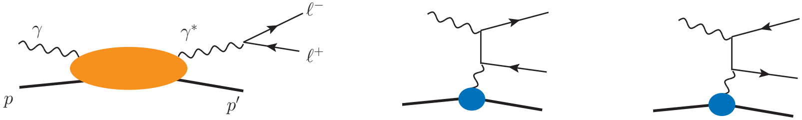


Difference between DVCS and TCS



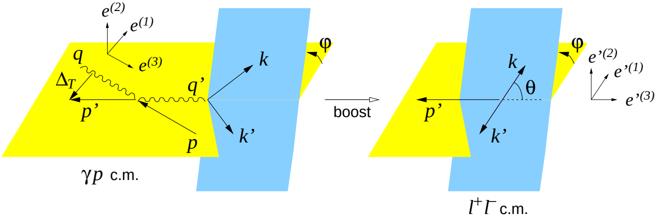
- at leading order in α_s: same amplitudes for DVCS and TCS (up to opposite phases)
- starting at NLO get differences (calculations are available)
- what to learn?
  - if can compare TCS and DVCS with precision
    $\rightsquigarrow$ detailed sensitivity to GPDs
    if only rough comparison
    $\rightsquigarrow$ consistency check of leading-twist dominance
    if cannot compare:
    $\rightsquigarrow$ take TCS as "substitute" for DVCS

Difference between DVCS and TCS: analysis



$$\frac{d\sigma_{\mathrm{TCS}}}{d(\cos\theta)\, dQ^2\, dt} : \frac{d\sigma_{\mathrm{BH}}}{d(\cos\theta)\, dQ^2\, dt} \sim \frac{1}{Q^2} : \frac{1}{\sin^2\theta}\,\frac{1}{t}$$

$\theta =$ polar angle of ℓ^+ in γ^* c.m.



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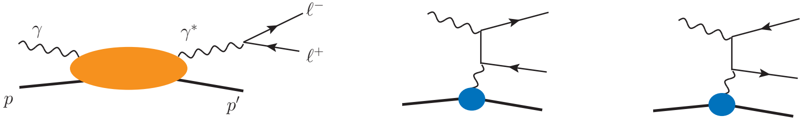

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- no analog of $1/y^2$ enhancement in DVCS

M.D., Berger, Pire, hep-ph/0110062

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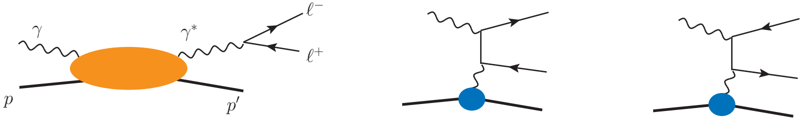
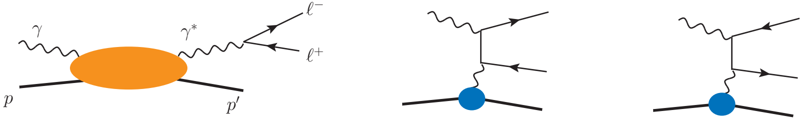


$$\frac{d\sigma_{\mathrm{TCS}}}{d(\cos\theta)\, dQ^2\, dt} : \frac{d\sigma_{\mathrm{BH}}}{d(\cos\theta)\, dQ^2\, dt} \sim \frac{1}{\tau^2} : \left|\mathsf{GPD}(\tau)\right|^2 \qquad \tau = \frac{Q^2}{s_{\gamma p}}$$

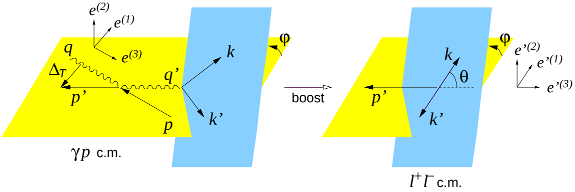
- for estimate take GPD$(\tau) \sim q(\tau)$
  $\rightsquigarrow$ at low enough τ TCS takes over

explicitly seen for LHC kinematics in:
Pire, Szymanowski, Wagner, arXiv:0811.0321
find break-even e.g. at $\sqrt{s} \sim 300\,\mathrm{GeV}$
for $Q^2 = 5\,\mathrm{GeV}^2$, $-t = 0.2\,\mathrm{GeV}^2$, $\pi/4 < \theta < 3\pi/4$

Difference between DVCS and TCS: analysis



- access interference term if can measure
  φ = angle between hadron and lepton plane



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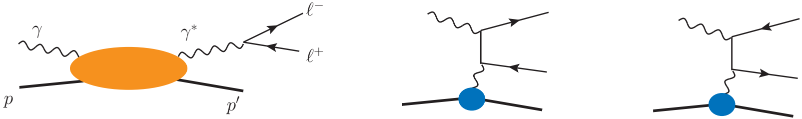
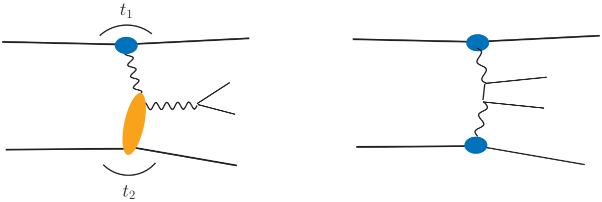


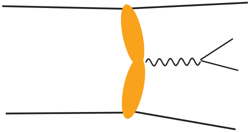
- access interference term if can measure
  $\varphi =$ angle between hadron and lepton plane
- get $\cos\varphi \ \sin^{-1}\theta \ \ \mathrm{Re}\,\mathcal{A}(\gamma p \to \gamma^* p)$
  (forward-backward asy. as analog of beam charge asy. in DVCS)
- access $\mathrm{Im}\,\mathcal{A}(\gamma p \to \gamma^* p)$ in single spin asymmetries
  (polarized γ or p)

From pp to γp



- get quasi-real photon from one proton
- in general can have γ from either proton, including interference between two cases
- ensure dominance of γ from one identified proton by selecting very small t_1, while t_2 of "typical hadronic size"

Case without photon exchange



- get same final state with strong-interaction exchange on *both* sides (enhance photon by small t_1)
- prod. of γ or vector meson $\rightarrow$ one exchange $C+$, other $C-$ at high energies proposed for searching odderon exchange
  for J/Ψ production see Bzdak, Motyka, Szymanowski, hep-ph/0702134

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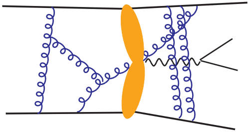

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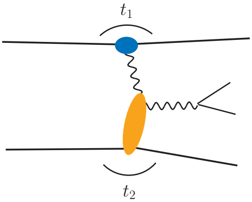
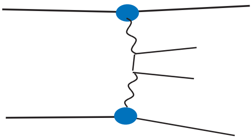
- for hadronic exchange have no factorization reinteractions suppress events with rapidity gaps

  diffraction at Tevatron: suppression by factor 10 and more
- similar mechanism to produce χ_c, glueball, Higgs, ... then $C+$ exchange on both sides dominant at high energies

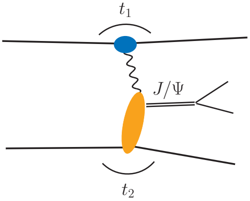
Back to photon exchange





- small t_1 $\leftrightarrow$ large impact parameter b ("ultraperipheral")
  $\rightsquigarrow$ QCD reinteractions not important
- can check in kinematic region where photon exchange on both sides dominates

J/Ψ production



- $\ell^+\ell^-$ not from γ^* but from J/Ψ for $M_{\ell^+\ell^-} = M_{J/\Psi}$
- Bethe-Heitler process then suppressed
  $\rightsquigarrow$ simple cross section measurement
- done at RHIC in Au+Au:
  Baltz, Klein, Nystrand, nucl-th/0205031; PHENIX arXiv:0903.2041
  estimates for J/Ψ and Υ: Klein, Nystrand, hep-ph/0310223

What could RHIC contribute for $\gamma p \to J/\Psi p$?

- existing data for σ and $d\sigma/dt$ from

Cornell (1975)	$\sqrt{s_{\gamma p}} =$	$4.5\,\mathrm{GeV}$
SLAC (1975)		$6\,\mathrm{GeV}$
FNAL E401		$10 - 24\,\mathrm{GeV}$
ZEUS		$20 - 290\,\mathrm{GeV}$
H1		$40 - 305\,\mathrm{GeV}$

  RHIC: opportunity for more precise t dependence correlated with $s_{\gamma p}$ at moderate energies?

- transverse target spin asymmetry

  calculable in GPD framework:

$$A_{UT}(\tau, t) \approx \frac{\sqrt{t_0 - t}}{m_p} \frac{\mathrm{Im}(\mathcal{E}^* \mathcal{H})}{|\mathcal{H}|^2} \qquad \tau = \frac{M^2_{J/\Psi}}{s_{e\gamma}}$$

$\mathcal{H}, \mathcal{E} =$ integrals over corresponding GPDs

$\rightsquigarrow$ information on helicity-flip distribution E for gluons

also discussed for EIC, but different timline, exp'tl conditions etc

Summary

possibilities for GPD physics in γp at RHIC

- J/Ψ production: transverse target spin asy. $\rightarrow E^g$
- timelike Compton scattering: detailed access to GPDs including $E^{q,g}$ if have transv. target pol.

Summary

possibilities for GPD physics in γp at RHIC

- J/Ψ production: transverse target spin asy. $\rightarrow E^g$
- timelike Compton scattering: detailed access to GPDs including $E^{q,g}$ if have transv. target pol.

experimental requirements:

- need enough rate/detection efficiency
- ensure exclusivity
- ensure very small t_1 for one proton (probably need to tag p)
- want to measure t_2 (other proton) and $s_{e\gamma}$
- for TCS also need hadronic ($\gamma p \rightarrow \ell^+ \ell^- p$) plane (need φ)

cannot estimate prospects without some numerical estimates